Monte Carlo simulation of a scanning whole body counter and the effect of BOMAB phantom size on the calibration.

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INTRODUCTION: *In Vivo* measurements use radiation detectors, such as NaI, that require calibration using a source that is both geometrically and materially similar to the actual sample to be measured. In the case of whole body counting, the sample being measured is a person. Traditionally, BOttle Mannikin ABsorber (BOMAB) phantoms have been used for this purpose. A BOMAB phantom usually consists of ten elliptical containers (bottles) so that when assembled it mimics a human form; the 95-percentile phantom consists of eleven containers, an adjustment made because of weight considerations. The BOMAB phantom has, by consensus opinion, been acclaimed as the de facto standard phantom for the calibration of whole body counting systems and an ANSI standard has since been published (American National Standards Institute/Health Physics Society. Specifications for the Bottle Manikin Absorption Phantom. McLean, VA: Health Physics Society; 1999).

The use of different sized BOMAB phantoms is important as it allows a facility to establish a calibration data set that can account for the variability in size of its workforce. For example, a recent study in Canada has shown that physical characteristics of male workers in the Uranium Industry can vary significantly. This study found that the height of male workers varied from 1.5 - 2.0 m, the weight varied from 50 - 150 kg, and the chest wall thickness varied from 1.9 - 6.6 cm over an age range of 23 - 63 yrs.

It is recognised that the purchase and use of a BOMAB phantom family can be both expensive and time consuming. The establishment of all the calibration curves corresponding to each phantom and over a wide energy range would requires a facility to: 1) purchase radioactive standards that cover the required energy range, 100 keV- 2 MeV. 2) Fill each phantom with a single radionuclide. 3) Develop the calibration sets. 4) Establish a correction factor methodology for persons of intermediate height and weight. However, there is an inexpensive alternative to the above: the counting efficiency of a whole body counter can be determined by Monte Carlo simulation. This paper has applied this technique to the HML's scanning detector whole body counter using all of the phantoms in the BRMD BOMAB phantom family.

METHODS AND MATERIALS: **Modelling of the BOMAB phantoms:** The HML uses BOMAB phantoms that simulate: a Reference four year old child, a Reference ten year old child, a five-percentile male, a Reference Female, a Reference Male, a 95-percentile male. The phantoms were measured to determine the height, semi-major, and semi minor axis of each phantom. The thickness of the high density polyethylene wall was 0.25 cm, except at the filling cap end where it was 1.5 cm. This data was used to construct a series of virtual BOMAB phantoms.

The Whole Body Counter: The HML's whole body counter is housed in a low background counting chamber constructed in 1959 by the Dominion Bridge Company using material supplied by the Steel Company of Canada. The chamber was installed in the Radiation Protection Bureau in 1960 and has been used in the Human Monitoring Program of the Health Canada for 40 years.

Subjects are counted in a supine position with their feet near the back wall of the counting chamber. The counting bed is of a tubular steel construction with a thick perspex sheet (1.0 cm) covered by a thin mattress (0.4 cm). The mattress is foam covered with a plastic cover. Disposable absorbent plastic backed paper is placed on the mattress before counting a phantom or subject. Only the bed, perspex sheet, and mattress were modelled.

The Detectors: The whole body counter is equipped with six NaI(Tl) detectors combined in two triangular arrays joined by a vertical travelling post. The upper array consists of three detectors that scan above and the lower array of three detectors scan below the subject. The upper array is on a moveable arm that can be raised from the bed surface to the roof of the counting chamber. The lower array is in a fixed geometry 12 cm below the bed.

Each detector in the upper and lower arrays is a cylindrical NaI(Tl) crystal that is nominally 12.7 cm in diameter and 10.2 cm high. The crystal is optically coupled to a low background photomuliplier tube. The outer casing of the detector is stainless steel 304 (Fe, 70%; Cr, 19%; Ni,11%; specific gravity, 8.02) which is 0.635 mm thick. The transmission of photons through the outer casing at 100 keV is 83% rising to 97% at 1000 keV.

Normally a subject is scanned from head to foot; however, MCNP cannot simulate a scanning system directly. Therefore, the scanning distance for each phantom was divided into ten sections. The locations of each detector were calculated for each position.

Only the detectors were modelled (i.e., the support mechanism was not modelled).

The Simulations: The following energies were simulated: 126 keV, 280 keV, 364 keV, 468 keV, 662 keV, 834 keV, 1173 keV, 1332 keV, 1460, 1836 keV and 2754 keV. Many photon energies were chosen to represent radionuclides frequently used in calibrations: ^{57}Co, ^{131}I, ^{137}Cs, ^{60}Co, ^{54}Mn, ^{40}K, ^{88}Y, ^{24}Na. The remaining energies are interpolations to fill in areas so that efficiency vs energy curves can be constructed.

Each photon energy was run independently and were mono-energetic for each of the ten counting positions. The photons that interacted with the NaI in the detectors were tallied individually so that an individual detector efficiency was obtained for each configuration. A scan was obtained by averaging the ten counting positions and a three-detector array was simulated by simply adding up the individual detector tallies for a given configuration.

Benchmark: The simulations were benchmarked by counting a Reference Man phantom with the detectors placed in each of the ten positions calculated for use in MCNP. The phantom contained 3928 Bq (3 Jan 2001) of ^{137}Cs. The phantom was also measured in the conventional way, i.e., scanning the detectors.

RESULTS AND DISCUSSION: **Counting Efficiency:** Fig. 1 shows the combined array (lower and upper) as a function of photon energy for all the virtual BOMAB phantoms.

Size Dependency: If all phantoms had the same efficiency at a given photon energy, the ratio of the counting efficiency of a given phantom to the male-sized phantom would be unity. The data show that this not to be the case - see Fig. 2.

As expected, the size dependency varies with photon energy with the largest deviations occurring at low photon energies. This data shows that if the default counting efficiency was applied to counting data from persons either much smaller or much larger than the male-sized phantom, a significant error would be introduced into the activity estimate. For example, the data from the four-year-old phantom shows that the error would be a factor of two or greater at most energies. This result is important for emergency monitoring only as this phantom is not representative of persons in the workforce.

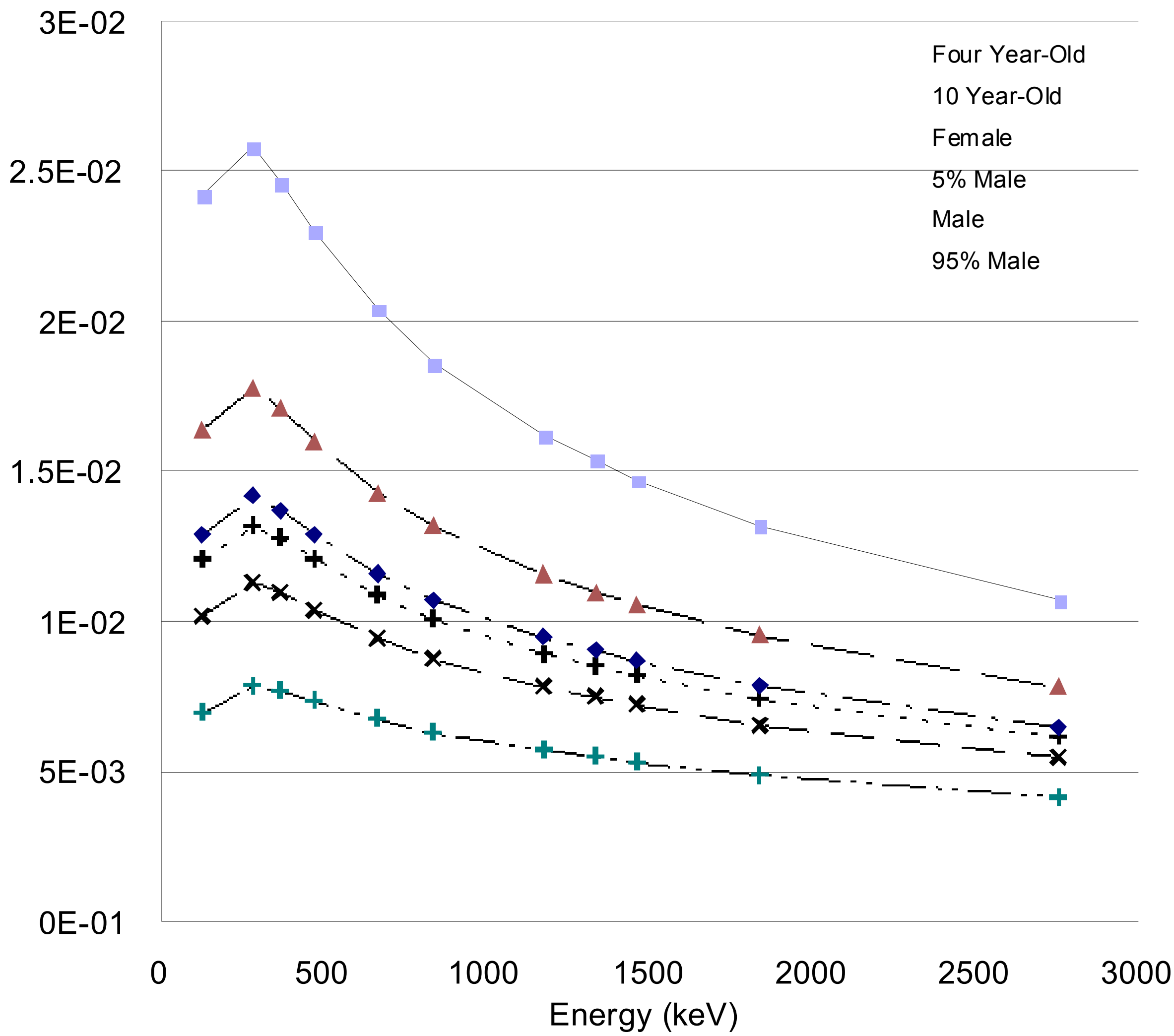
The 95-percentile phantom, however, is typical of some workers. The data obtained from this phantom shows that large persons emit fewer photons, presumably to self-attenuation. If such a person were measured using the default calibration factors (male-sized) then any activity estimate will be a factor of 1.35 to 1.51 lower than the true value.

Smaller persons than what is represented by the male-sized phantom can expect to have their activity estimate inflated by approximately 20%. Currently the dose limits in Canada are 100 mSv in a five-year period with a yearly maximum of 50 mSv. Operationally 20 mSv is used for planning purposes. Under these conditions, a 20% overestimate becomes a significant factor.

Benchmark: The results of counting the male-sized phantom containing ^{137}Cs at each of the ten positions used in the MCNP stimulations were compared with the ratio of the calculated to measured counting efficiency at each position. The scanning counting efficiency was also compared. The agreement between calculated and measured counting efficiencies was excellent. The ratio of the counting efficiencies (measured/calculated) varies from 0.93 to 1.09 with an average value of 1.00 " 0.06. The agreement between the scanning counting efficiency and the average counting efficiency from the ten positions is 0.96 and 0.97 for the measured and calculated efficiencies, respectively.

CONCLUSIONS: This presentation has shown that Monte Carlo simulations offer an inexpensive alternative to estimate the size dependency of a given whole body counting system. In this case a scanning detector array configuration. Size dependency factors vary with both phantom size and photon energy. Correction factors lie in the region of 2.4 to 0.66 depending on size and energy. It has also shown that a scanning detector (or presumably a scanning bed) counting system can be satisfactorily simulated by putting the detector in different places relative to the phantom and averaging the results. This technique was verified by experimental work that obtained an agreement of 96% between scanning and averaging. The simulations were also benchmarked by comparing experimental results with theoretical predictions. The agreement was 97%.

1: Counting efficiency of the combined arrays for each virtual phantom as a function of photon



2: Ratio of the counting efficiency of a given phantom to the male-sized phantom as a function